

The Study of Forest Management Evaluation System Based on the Improvement of Wildlife Habitat Quality

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Abstract

With the intensification of global climate change and human activities, forest ecosystems face issues such as structural simplification, habitat fragmentation, and biodiversity decline. Traditional forest management evaluation systems, which focus primarily on timber production or single ecological functions, are no longer sufficient to comprehensively reflect the impact of forest management measures on wildlife habitat quality and ecosystem stability. In response to meet the need for the transformation of forest management from resource utilization to ecosystem health and biodiversity conservation, constructing a forest management evaluation system centered on improving wildlife habitat quality has significant theoretical and practical implications. Based on relevant theories in ecology, landscape ecology, and forest management, a three-tier evaluation system was developed (goal layer, criterion layer, indicator layer). Through literature analysis, expert consultations, and the Analytic Hierarchy Process (AHP), 35 core evaluation indicators were selected from four dimensions: biodiversity, forest structure, ecological functions, and socio-economic & management. A weighted composite evaluation model was constructed to quantitatively assess the impact of forest management measures on habitat quality. The system's applicability and sensitivity were tested in the Yanshan-Taihang Mountain forest area, using plot surveys, wildlife monitoring, and statistical data. 1) Biodiversity and forest structure indicators had higher weights, making them the primary drivers of habitat quality variation in the study area; 2) Ecological function indicators played a sustained role in supporting habitat quality, reflecting the stability and resilience of the forest ecosystem; 3) Socio-economic and management indicators contributed less individually but were essential for regulating human disturbances and ensuring the long-term improvement of habitat quality. Overall, the evaluation system

accurately reflected the changes in forest habitat quality under different management scenarios. This study emphasizes the improvement of wildlife habitat quality as the core objective of forest management evaluation. The developed multi-dimensional evaluation system is ecologically oriented and highly operational, offering a scientific basis for near-natural forest management, habitat restoration, and the optimization of forest management plans.

Keywords

Forest Management, Habitat Quality, Wildlife, Analytic Hierarchy Process, Evaluation System

1. Introduction

Forest ecosystems are the most biodiverse and ecologically complex component of terrestrial ecosystems, playing an irreplaceable role in maintaining regional ecological security, regulating climate change, conserving water resources, and cycling carbon and oxygen [1]-[5]. However, influenced by intensified global climate change, land-use changes, and long-term single-function management practices [6], issues such as structural simplification, habitat fragmentation, and ecological function degradation have become increasingly prominent [7]-[9]. The loss of wildlife habitats and the decline of species populations have become key indicators of forest ecosystem degradation [10]-[12].

Traditional forest management evaluation systems primarily focus on timber yield, forest growth, or singular ecological service functions. While these systems can partially reflect management performance, they fall short in addressing habitat heterogeneity, the complexity of microhabitat structures, and the response of wildlife communities. Consequently, they are unable to comprehensively demonstrate the impact of forest management measures on biodiversity conservation and ecosystem stability [13] [14]. In the context of strengthening ecological civilization and biodiversity conservation, forest management objectives are gradually shifting from resource production towards ecosystem health and multifunctional synergy. However, the evaluation systems that align with these objectives remain relatively underdeveloped [15]-[19]. In 2024, the Chinese government published the “China National Biodiversity Conservation Strategy and Action Plan (2023-2030)”, which calls for the establishment of foundational biodiversity datasets, including species distribution data [16].

Wildlife habitat quality comprehensively reflects the forest’s structural characteristics, ecological function status, and the level of anthropogenic disturbance [19]-[21]. It is a critical indicator for assessing the integrity and stability of forest ecosystems. Focusing on the improvement of habitat quality as the core goal of forest management evaluation helps systematically examine the ecological effects of management measures from a biological response perspective and provides scientific feedback for optimizing management models [22]-[25]. Therefore, con-

structuring a forest management evaluation system oriented towards improving wildlife habitat quality is important in driving the transformation of forest management philosophy and enhancing biodiversity protection efforts.

2. Materials and Methods

2.1. Study Area

The Yanshan-Taihang Mountain forest area is located in the northern farming-pastoral and forestry-grassland transition zones of China. It is a critical ecological security barrier for North China and a key area for wildlife distribution. The topography of the study area consists primarily of mid-low mountains and hills, with elevations ranging between 500 and 2000 meters. The region exhibits complex landforms and diverse habitat units. It is characterized by a temperate monsoon climate, with an annual average temperature of approximately 4°C - 10°C and annual precipitation ranging from 400 to 700 mm, with uneven seasonal distribution.

The regional forest vegetation is dominated by mixed coniferous and broadleaf forests, with key species including Chinese pine (*Pinus tabulaeformis*), North China larch (*Larix principis-rupprechtii*), oaks (*Quercus* spp.), and birch (*Betula* spp.). The forest structure exhibits significant variation due to historical management practices and human activity. The area has considerable research value for studying habitat quality improvements, with diverse management types and structural differences.

2.2. Data Sources

The study data were collected from three primary sources: 1) Forest Resource Data: Sourced from continuous forest surveys and plot investigations [26]-[28]. 2) Wildlife Data: Obtained from transect surveys, infrared camera monitoring, and historical records. 3) Management and Socio-Economic Data: Sourced from forestry management departments' statistical records and field interviews.

A "Transect-Plot-Quadrat" nested survey and monitoring system is set up, where the transects cover the plots. In each experimental area, 9 to 12 transects are established, each ranging from 500 to 1000 meters in length and 5 meters in width. Each forest type is divided into three management treatments (control, conventional management, biodiversity-oriented management), with three replications per treatment, totaling nine plots. The size of each plot is either 20 m × 30 m or 30 m × 30 m, with the plot groups arranged along the vertical contour lines. A total of 27 to 36 plots are established. One infrared camera is deployed in the center or a typical location of each plot. In each plot, 1 to 3 shrub quadrats (5 m × 5 m) and 3 herb quadrats (1 m × 1 m) are set up to conduct plant diversity surveys.

3. Development of the Evaluation Indicator System

3.1. Construction Approach

Habitat quality is a multi-dimensional and scale-dependent concept, and a single

indicator is insufficient to fully reflect its variation [13] [21]. This study centers on improving wildlife habitat quality as the primary goal and adopts a layered construction approach that balances ecological significance and data accessibility. A multi-tiered evaluation system was developed, comprising a goal layer, a criterion layer, and an indicator layer [29] [30].

3.1.1. Structure of the Indicator System

The evaluation system includes:

- Goal Layer: Overall improvement of wildlife habitat quality through forest management.
- Criterion Layer: Comprising four main dimensions—biodiversity, forest structure, ecological functions, and socio-economic and management factors.
- Indicator Layer: Comprising 35 specific indicators across these dimensions.

This system systematically reflects how forest management measures, through structural adjustments, functional support, and management constraints, impact habitat quality. The goal layer reflects the comprehensive effect of forest management measures on improving habitat conditions, enhancing ecosystem support capacity, and stabilizing wildlife populations. The criterion layer systematically divides the key factors influencing habitat quality across biodiversity, ecological structure, ecological function, and socio-economic management.

3.1.2. Indicator Selection and Ecological Significance

The indicator system encompasses various factors influencing habitat quality:

- Biodiversity: Includes plant and animal species richness, diversity indices, and the frequency of indicator species [31]-[35].
- Forest Structure: Includes indicators such as canopy closure, species mixture, and structural diversity (e.g., the proportion of large-diameter trees, standing deadwood density) [36]-[40].
- Ecological Functions: Includes indicators related to productivity, soil health, hydrological functions, and carbon storage [18] [41].
- Socio-Economic and Management Factors: Includes the implementation of management measures, community participation, ecological compensation, and forest product utilization [42]-[45].

These indicators (**Table 1**) were selected based on a thorough literature review, expert consultations, and the ability to obtain reliable data from the study area. The selection ensures a comprehensive representation of both ecological and management dimensions.

Table 1. Comprehensive evaluation system for forest management oriented to wildlife habitat quality.

Criterion Layer	Indicator ID	Indicator Name	Ecological Significance	Calculation Formula
Biodiversity B_1	C_1	Plant Species Richness	Reflects the capacity of habitat plant resource supply	$C_1 = S_p$
	C_2	Plant Diversity Index	Characterizes community composition evenness and stability	$C_2 = -\sum_{i=1}^s p_i \ln p_i$

Continued

	C_3	Animal Species Richness	Directly reflects habitat suitability	$C_3 = S_a$
	C_4	Animal Diversity Index	Indicates the structural complexity of animal communities	$C_4 = -\sum_{i=1}^S p_i \ln p_i$
	C_5	Frequency of Indicator Species Occurrence	Indicates the presence of high-quality habitats	$C_5 = n_i / N$
	C_6	Number of Protected Species Records	Reflects the conservation importance of the habitat	$C_6 = N_p$
	C_7	Functional Group Diversity Index	Represents niche differentiation and functional complementarity	$C_7 = -\sum_{j=1}^G q_j \ln q_j$
	C_8	Stand Canopy Closure	Reflects canopy structure and shading conditions	$C_8 = \sum A_c / A$
	C_9	Vertical Structural Layer Index	Indicates the complexity of three-dimensional habitats	$C_9 = L$
	C_{10}	Diameter Class Diversity Index	Reflects uneven-aged stand structure characteristics	$C_{10} = -\sum_{k=1}^D r_k \ln r_k$
	C_{11}	Proportion of Large-Diameter Trees	Provides key habitat and foraging resources	$C_{11} = N_{dbh \geq d_0} / N$
	C_{12}	Tree Species Mixing Degree	Enhances habitat heterogeneity	$C_{12} = \frac{1}{n} \sum_{i=1}^n \frac{m_i}{k}$
Forest Structure B_2	C_{13}	Density of Standing Dead Tree	Provides cavities and saproxylic habitats	$C_{13} = N_{snag} / A$
	C_{14}	Density of Downed Dead Wood	Enhances ground-level microhabitats	$C_{14} = N_{fallen} / A$
	C_{15}	Forest Gap Ratio	Provides space for regeneration and foraging	$C_{15} = A_{gap} / A$
	C_{16}	Patch Heterogeneity Index	Reflects landscape diversity	$C_{16} = -\sum_{i=1}^n p_i \ln p_i$
	C_{17}	Landscape Fragmentation Index	Indicates habitat continuity	$C_{17} = L / A$
	C_{18}	Edge Density	Influences species edge effects	$C_{18} = E / A$
	C_{19}	Ecological Corridor Connectivity	Ensures species migration and dispersal	$C_{19} = 2(N_e - N_i) / N_i$
Ecological Functions B_3	C_{20}	Stand Net Primary Productivity (NPP)	Represents energy supply capacity	$C_{20} = \Delta B + L$
	C_{21}	Soil Organic Matter Content	Reflects soil fertility	$C_{21} = m_{om} / m_s$
	C_{22}	Litter Layer Thickness	Influences nutrient cycling and microhabitats	$C_{22} = \frac{1}{n} \sum h_i$
	C_{23}	Water Conservation Capacity	Maintains habitat water stability	$C_{23} = A \times R \times K$
	C_{24}	Forest Carbon Storage	Indicates ecosystem stability	$C_{24} = \sum b_i \times CF$
	C_{25}	Disturbance Resistance Index	Reflects system resilience	$C_{25} = H' / D$

Continued

	C_{26}	Implementation of Management Measures	Indicates the degree of management implementation	$C_{26} = A_{NN} / A$
	C_{27}	Community Participation Level	Influences long-term management effectiveness	$C_{27} = N_{part} / N_{total}$
	C_{28}	Degree of Ecological Compensation Implementation	Reflects institutional support	$C_{28} = F_{act} / F_{plan}$
	C_{29}	Management Cost Investment Intensity	Reflects the level of financial input ensuring management effectiveness	$C_{29} = C_{input} / A$
Socio-Economic and Management B_4	C_{30}	Comprehensive Benefit of Forest Management	Indicates economic sustainability	$C_{30} = V_{timber} + V_{NTFP}$
	C_{31}	Proportion of Forest Product Utilization	Reflects resource utilization patterns	$C_{31} = Q_s / Q_t$
	C_{32}	Number of Jobs Created	Indicates social benefits	$C_{32} = n_{person} / T$
	C_{33}	Monitoring and Evaluation Frequency	Ensures scientific management	$C_{33} = n_{monitor} / T$
	C_{34}	Level of Technical Standardization	Reflects management standardization	$C_{34} = n_{std} / n_{req}$
	C_{35}	Consistency of Management Objectives	Indicates coordination among multiple objectives	$C_{35} = 1 - \frac{1}{n} \sum G_i - G_r $

Note: Standing dead tree (SDT) and downed dead wood (DDW), as key structural components of forest ecosystems, provide nesting sites, shelter, and food resources for a wide range of birds, mammals, and invertebrates. Their abundance and spatial distribution are widely regarded as important indicators of forest habitat quality and the degree of near-naturalness [46] [47]. The calculation methods for the evaluation indicators listed in **Table 1** are derived from commonly accepted definitions in forestry and ecology, and they systematically characterize forest habitat quality from multiple dimensions, including biological composition, forest structure, ecological functions, and management practices. Each indicator is first calculated based on plot surveys, monitoring data, or statistical records, and then rendered dimensionless using the min-max normalization method to eliminate the effects of differences in units and orders of magnitude among indicators.

3.2. Weight Determination and Composite Evaluation Model

3.2.1. Weight Determination Using the Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) was employed to determine the relative weights of the indicators in the evaluation system. A pairwise comparison matrix was constructed using the 1 - 9 scale method proposed by Saaty, and the consistency of the judgments was tested [48]. To ensure the scientific validity of the weight allocation, it is recommended to consult 15 experts, covering the fields of forest ecology, wildlife conservation, and forest management, including 8 professors/researchers and 7 senior engineers. The Analytic Hierarchy Process (AHP) will be employed to calculate the weights of the evaluation indicators, with consistency checks performed to ensure the reliability of the results, thereby guaranteeing the scientific and rational distribution of the weights. The resulting weight values (**Table 2**) reflect the relative importance of each indicator in the overall evaluation system [48] [49].

Table 2. Weighting and direction of evaluation system indicators.

Criterion Layer	Criterion Layer Weight	Indicator ID	Indicator Weight	Indicator Direction
B1	0.34	C1	0.042	+
		C2	0.04	+
		C3	0.05	+
		C4	0.046	+
		C5	0.042	+
		C6	0.038	+
		C7	0.034	+
B2	0.29	C8	0.028	+
		C9	0.032	+
		C10	0.032	+
		C11	0.032	+
		C12	0.034	+
		C13	0.032	+
		C14	0.03	+
		C15	0.026	+
		C16	0.022	+
		C17	0.018	-
		C18	0.014	+
		C19	0.02	+
B3	0.22	C20	0.036	+
		C21	0.032	+
		C22	0.026	+
		C23	0.028	+
		C24	0.032	+
		C25	0.036	+
B4	0.15	C26	0.03	+
		C27	0.026	+
		C28	0.024	+
		C29	0.022	+
		C30	0.02	+
		C31	0.018	+
		C32	0.014	+
		C33	0.016	+
		C34	0.016	+
		C35	0.012	+

$$A = (a_{ij})_{n \times n} . \quad (1)$$

In this context, a_{ij} represents the relative importance of the i -th indicator

compared to the j -th indicator, satisfying the conditions: $a_{ij} > 0$, $a_{ji} = 1/a_{ij}$, and $a_{ii} = 1$.

Once the judgment matrix is constructed, the weights of the indicators are calculated using the eigenvector method. Let λ_{\max} denote the maximum eigenvalue of the judgment matrix, and W be the corresponding eigenvector. After normalization, the indicator weight vector is obtained.

To ensure the logical consistency of the expert judgments, a consistency test is performed on the judgment matrix. The consistency index (CI) and consistency ratio (CR) are calculated using the following formulas:

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \quad CR = \frac{CI}{RI}. \quad (2)$$

where RI is the random consistency index. If $CR < 0.10$, the judgment matrix passes the consistency test, indicating that the weight distribution is logically consistent and statistically reasonable. Otherwise, the judgment matrix needs to be revised. In this study, all hierarchical judgment matrices satisfy the consistency test requirements.

3.2.2. Standardization of Indicators

To ensure comparability between indicators with different units and scales, all data were standardized using an extreme value normalization method. This transformation ensures that each indicator contributes on a comparable scale, eliminating the effects of dimensional differences.

$$x'_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}. \quad (3)$$

3.2.3. Composite Evaluation Index

The composite habitat quality index (HQI) was calculated by summing the weighted, standardized values of each indicator. This index provides a quantitative measure of habitat quality, with higher values indicating better habitat conditions. The formula for the composite evaluation index is as follows:

$$HQI = \sum_{i=1}^n w_i x'_i. \quad (4)$$

where:

- w_i is the weight of indicator i ,
- x'_i is the standardized value of indicator i ,
- n is the total number of indicators.

4. Results

The evaluation system was applied to the Yanshan-Taihang Mountain forest area to test its sensitivity and applicability under different forest management scenarios. Data from plot surveys, wildlife monitoring, and statistical records were used to evaluate the habitat quality index across various management scenarios. The results (Table 3) were analyzed to identify key drivers of habitat quality improvement and to assess the sensitivity of the system to different forest management practices.

Table 3. Results of evaluation system indicators.

Criterion Layer	Criterion Layer Weight	Indicator ID	Indicator Weight	Indicator Direction	Min Value	Max Value	Measurement value	Standardized value	Contribution Value
B1	0.34	C1	0.042	+	10	150	120	0.786	0.0330
		C2	0.04	+	1	4.5	4.15	0.900	0.0360
		C3	0.05	+	5	80	64	0.787	0.0394
		C4	0.046	+	0.5	3.5	3	0.833	0.0383
		C5	0.042	+	0	1	0.75	0.750	0.0315
		C6	0.038	+	0	20	15	0.750	0.0285
		C7	0.034	+	0.2	1	0.9	0.875	0.0298
B2	0.29	C8	0.028	+	0.3	0.9	0.75	0.750	0.0210
		C9	0.032	+	2	5	4.55	0.850	0.0272
		C10	0.032	+	0.5	2	1.65	0.767	0.0245
		C11	0.032	+	0	30	22.5	0.750	0.0240
		C12	0.034	+	0.3	0.9	0.9	1.000	0.0340
		C13	0.032	+	0	30	22.5	0.750	0.0240
		C14	0.03	+	0	50	37.5	0.750	0.0225
		C15	0.026	+	0.05	0.3	0.26	0.840	0.0218
		C16	0.022	+	0.3	0.9	0.9	1.000	0.0220
		C17	0.018	-	0.1	0.6	0.36	0.480	0.0086
		C18	0.014	+	10	80	64	0.771	0.0108
		C19	0.02	+	0	1	0.75	0.750	0.0150
B3	0.22	C20	0.036	+	200	1000	900	0.875	0.0315
		C21	0.032	+	10	80	68	0.829	0.0265
		C22	0.026	+	2	10	9	0.875	0.0228
		C23	0.028	+	200	1500	1248	0.806	0.0226
		C24	0.032	+	30	300	248	0.807	0.0258
		C25	0.036	+	0.2	0.8	0.75	0.917	0.0330
B4	0.15	C26	0.03	+	0.2	0.9	0.8	0.857	0.0257
		C27	0.026	+	0.1	0.9	0.75	0.813	0.0211
		C28	0.024	+	0.1	0.8	0.65	0.786	0.0189
		C29	0.022	+	0	2.5	1.8	0.720	0.0158
		C30	0.02	+	0.5	0.8	0.65	0.500	0.0100
		C31	0.018	+	0.3	0.8	0.6	0.600	0.0108
		C32	0.014	+	1	50	36	0.714	0.0100
		C33	0.016	+	1	12	10	0.818	0.0131
		C34	0.016	+	0.1	0.9	0.75	0.813	0.0130
		C35	0.012	+	0.2	0.9	0.8	0.857	0.0103

4.1. Contribution of Biodiversity Indicators

The biodiversity dimension, which includes indicators such as plant and animal species richness, diversity indices, and indicator species frequency, played a significant role in the overall evaluation of habitat quality. The standardized values and contribution rates of these indicators emphasize the importance of species richness and diversity in driving habitat quality improvements (Figure 1). Figure 1 shows the normalized values and contribution values of various biodiversity indicators.

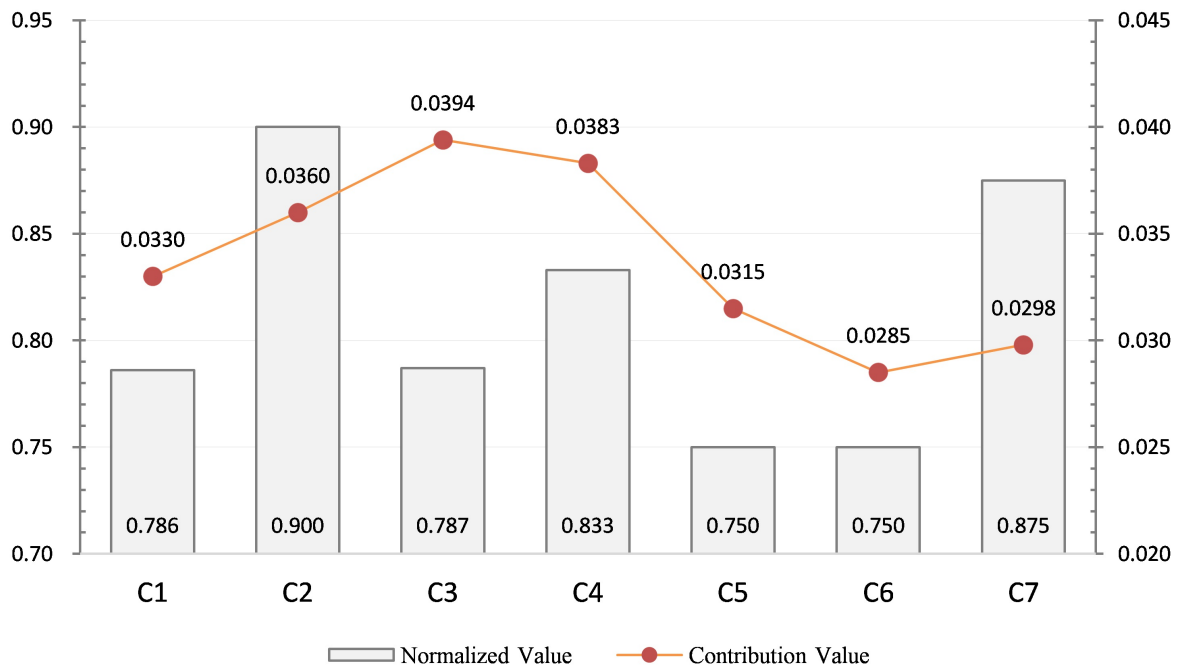


Figure 1. Graph of biodiversity indicators value.

- **Plant Species Richness:** The standardized value for plant species richness was 0.786, indicating that plant species diversity plays a crucial role in improving habitat quality. It was one of the key drivers of biodiversity in the study area.
- **Animal Species Richness:** Similarly, the standardized value for animal species richness was 0.787, which reflects a high level of animal diversity in the study area. This indicator also demonstrated a significant impact on the overall habitat quality evaluation.
- **Animal Diversity Index:** The standardized value for the animal diversity index was 0.833, suggesting that the diversity of animal communities contributes to maintaining the complexity and functionality of the habitat. Though it slightly lagged behind plant species richness, it was still a critical factor for the habitat's overall quality.
- **Frequency of Indicator Species:** The standardized value for the frequency of indicator species was 0.750, indicating that while this indicator positively in-

fluences habitat quality, its contribution was somewhat lower compared to species richness. This is likely due to the slower response of indicator species to ecological changes.

Overall, the biodiversity dimension made a significant contribution to the habitat quality index (contribution value: 0.2365), with plant and animal species richness being the dominant contributors. These results emphasize the core role of biodiversity in determining habitat quality in the study area.

4.2. Contribution of Ecological Structure Indicators

The ecological structure dimension, which includes indicators such as canopy closure, species mixture, and landscape fragmentation, had a significant impact on habitat quality. This dimension accounted for 25.54% of the overall contribution to the habitat quality index (Figure 2). Figure 2 presents a graph displaying the normalized values and contribution values of ecological structure indicators.

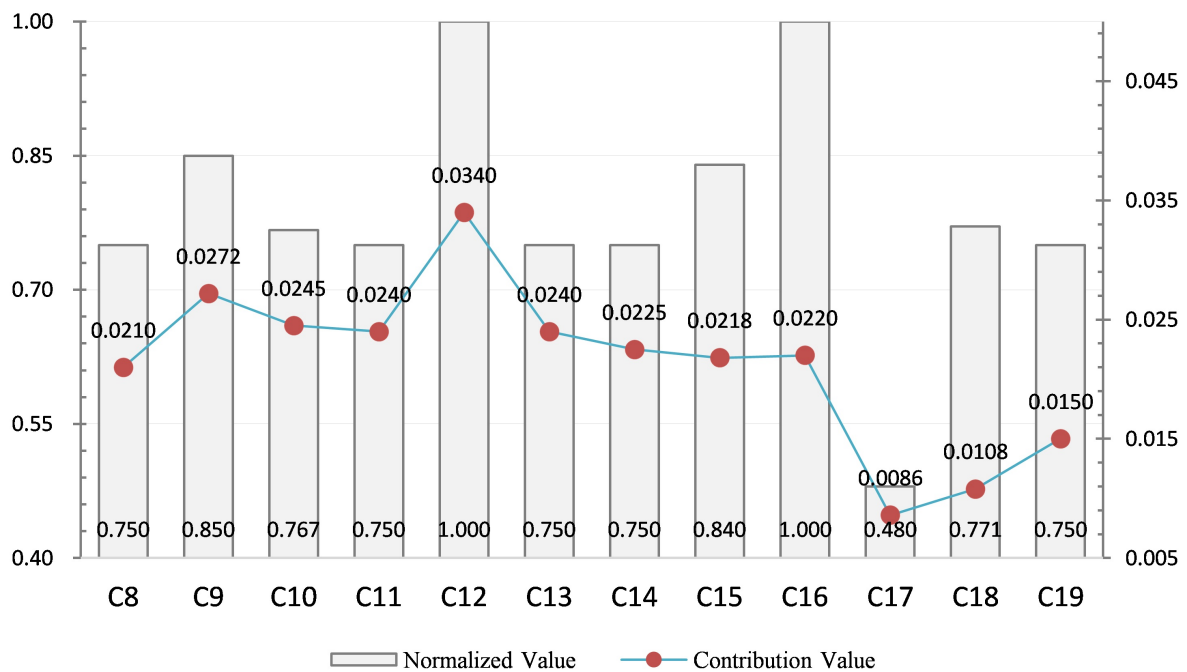


Figure 2. Graph of ecological structure indicators.

- Canopy Closure: The canopy closure index had a high contribution (0.750), reflecting the importance of forest cover in providing suitable shelter and regulating microhabitats for wildlife.
- Species Mixture: The species mixture index, with a standardized value of 1, highlighted the significant positive effect of mixed-species forests on habitat complexity and biodiversity. This indicator was essential in promoting habitat heterogeneity.
- Landscape Fragmentation: The landscape fragmentation index had a stand-

ardized value of 0.480, which was one of the few negative indicators. It reflects the degree of habitat fragmentation in the study area, which limits the movement and population stability of wildlife. This index emphasizes the need to improve habitat connectivity and reduce fragmentation.

The presence of large-diameter trees, standing dead tree, and downed dead wood also contributed to the habitat quality by providing critical resources for various species, including nesting sites, shelter, and food. These features play a vital role in maintaining ecological diversity.

4.3. Contribution of Ecological Function Indicators

The ecological function dimension, which evaluates the forest's role in energy production, soil health, water retention, and carbon storage, contributed 16.22% to the overall habitat quality index (Figure 3). Figure 3 presents a graph comparing the normalized values and contribution values of ecological function indicators.

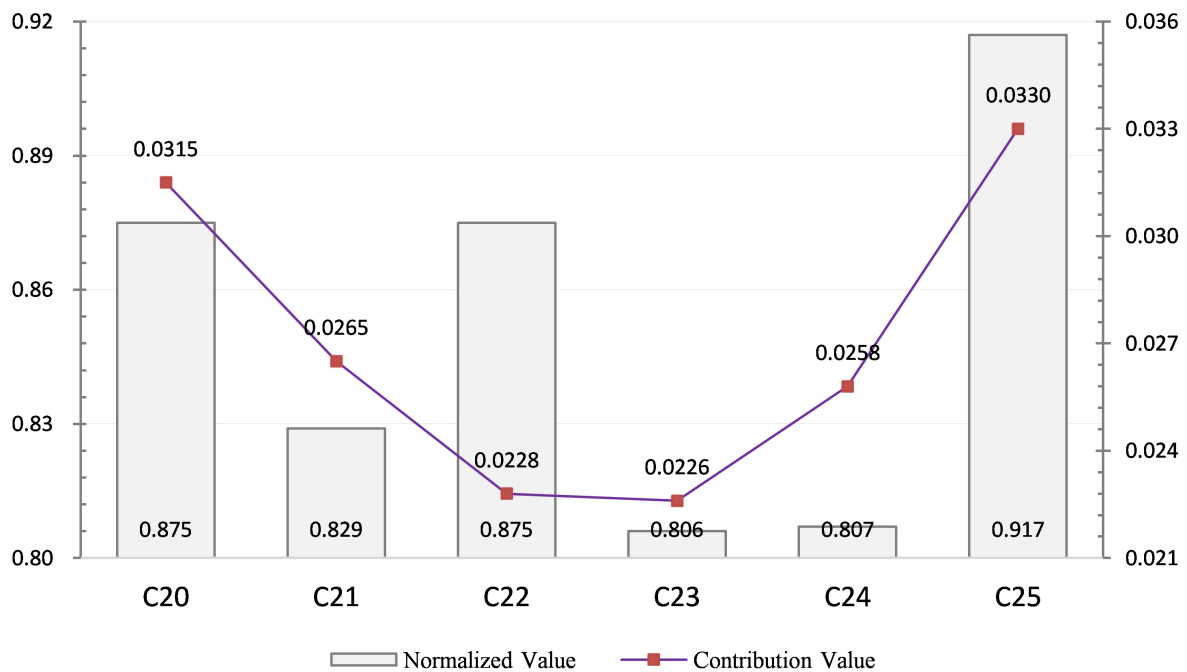


Figure 3. Graph of ecological function indicators.

- Net Primary Productivity (NPP): The standardized value for NPP was 0.875, indicating the forest's high capacity for energy production. This high productivity supports the entire forest ecosystem and is vital for sustaining biodiversity.
- Soil Organic Matter Content: The standardized value for soil organic matter content was 0.829, reflecting the forest's ability to maintain soil fertility and support plant life, which in turn enhances the habitat quality for wildlife.
- Water Conservation Capacity: The standardized value for water conservation

capacity was 0.806, highlighting the forest's role in stabilizing water availability and supporting wildlife habitat during dry periods.

While these indicators had a moderate impact, the results demonstrate that ecological functions like water retention and soil quality are fundamental for sustaining habitat quality, particularly in maintaining long-term ecosystem stability.

4.4. Contribution of Socio-Economic and Management Indicators

The socio-economic and management dimension, which includes factors such as the implementation of management measures, community participation, and ecological compensation, contributed the least (14.87%) to the overall habitat quality evaluation (Figure 4). Figure 4 presents a graph illustrating the normalized values and contribution values of socio-economic and management indicators.

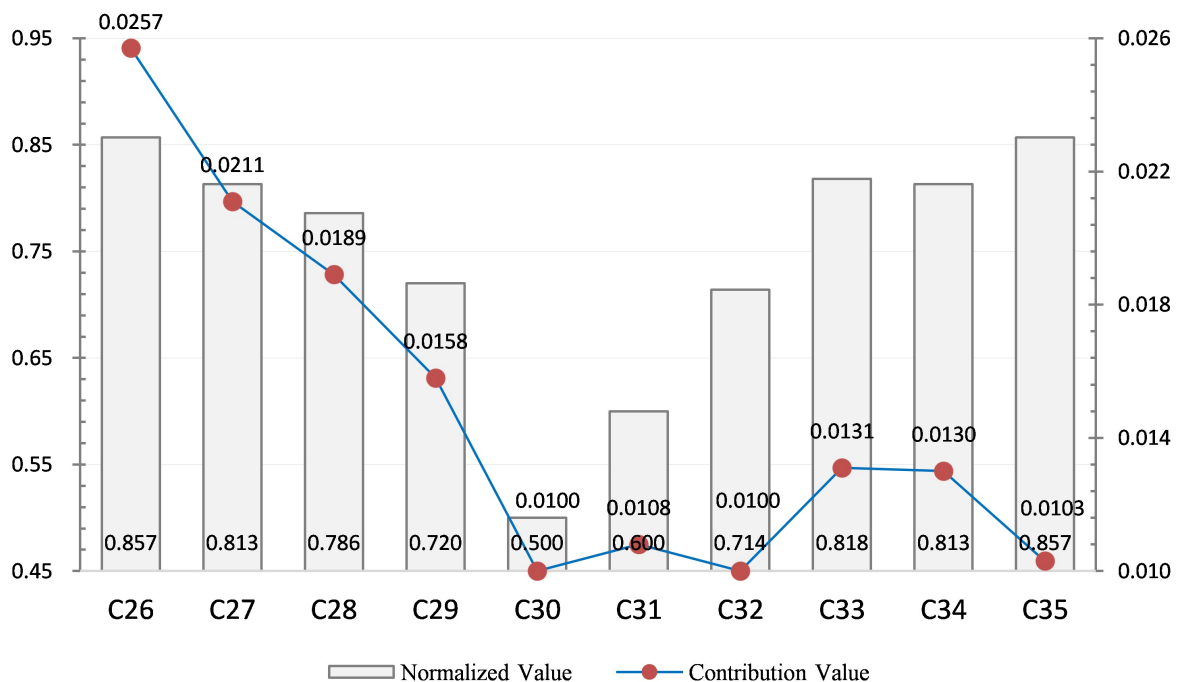


Figure 4. Graph of socio-economic and management indicators.

- **Implementation of Management Measures:** The standardized value for the implementation rate of forest management measures was 0.857, indicating that effective management practices are vital for ensuring habitat quality.
- **Community Participation:** The standardized value for community participation was 0.813, emphasizing the role of local involvement in forest management and ecosystem restoration efforts.
- **Ecological Compensation:** The ecological compensation index, with a standardized value of 0.786, showed that while compensation measures are important, their effectiveness still requires improvement.

Despite their lower contribution, socio-economic and management indicators

were essential for regulating human impacts and ensuring the long-term improvement of habitat quality. The results underscore the importance of sustainable management and the integration of local communities in the conservation process.

4.5. Overall Habitat Quality Evaluation

Using the composite HQI, the study area was classified into five habitat quality categories: high, relatively high, moderate, relatively low, and low (Table 4). The HQI values for the study area ranged between 0.80 and 0.89, with a mean value of approximately 0.803, indicating that the overall habitat quality in the area is relatively high.

Table 4. Classification of habitat quality based on HQI scores.

Level	Description	Score Range	Ecological Characteristics	Management Recommendations
High	Pristine/Reference Habitat	[0.90, 1.00]	Ecosystem structure is complete and complex; biodiversity is rich; ecological functions are strong; close to original climax community state	Core conservation area; implement strict protection and avoid human disturbance
Relatively High	Sub-climax/Healthy Habitat	[0.80, 0.89]	Ecosystem is healthy and stable; key structural and functional indicators are good; biodiversity remains at a relatively high level	Important ecological support area; suitable for protection-oriented management with minimal intervention and natural restoration
Moderate	General/Recovering Habitat	[0.70, 0.79]	Ecosystem is in moderate or early recovery stage; some structural or functional limitations exist (e.g., low tree species diversity, insufficient connectivity); has restoration potential	Priority area for habitat restoration; implement targeted cultivation and connectivity enhancement measures
Relatively Low	Degraded/Damaged Habitat	[0.50, 0.69]	Ecosystem is clearly degraded or damaged; structure and function are simplified; biodiversity is low; resilience to disturbance is weak	Require active and systematic ecological restoration projects, such as planting, corridor construction, and soil improvement
Low	Severely Degraded/Vulnerable Habitat	[0, 0.49]	Ecosystem is severely degraded; most natural functions are lost; habitat is highly fragmented or simplified; may include newly afforested land or heavily disturbed sites	Initiate major ecological reconstruction or long-term protective closure

Notes: HQI is a composite metric ranging from 0 to 1, reflecting habitat integrity, biodiversity, ecosystem function, and resilience. Higher HQI values indicate higher-quality habitats closer to reference or climax conditions.

The results showed that the forest management practices in the study area have led to substantial improvements in habitat quality, especially in terms of biodiversity and ecological structure. However, challenges remain in enhancing the ecological functions and socio-economic factors that support long-term habitat improvement.

5. Discussion

This study introduces a novel forest management evaluation system focused on improving wildlife habitat quality, addressing the gap in traditional systems that primarily evaluate forest performance through timber yield or single ecological functions. The findings highlight the critical role of biodiversity, forest structure, and ecological functions in shaping habitat quality, providing new insights into the interaction between forest management and ecosystem health.

5.1. Ecological Indicators and Habitat Quality

The results underscore the importance of biodiversity and forest structure in determining habitat quality. Biodiversity, particularly plant and animal species richness, was the dominant factor driving habitat quality variations in the study area. This finding aligns with previous studies that emphasize biodiversity as a fundamental driver of ecosystem functioning and resilience. Plant and animal diversity contribute significantly to the stability and adaptability of ecosystems, which are essential for maintaining the ecological services that support wildlife populations.

The contribution of forest structure indicators—such as canopy closure, species mixture, and the proportion of large-diameter trees, standing dead tree, and downed dead wood—further reinforces the importance of habitat heterogeneity. These features create diverse microhabitats that support a wide range of species, improving ecosystem complexity and biodiversity. Our findings suggest that enhancing forest structural complexity should be a priority in forest management practices, especially in regions facing habitat degradation due to over-exploitation and fragmentation.

However, the landscape fragmentation indicator revealed a limitation in the study area's ecological connectivity. The relatively low contribution of this negative indicator (landscape fragmentation index) suggests that despite improvements in forest structure, habitat connectivity remains a challenge. Fragmented habitats hinder the movement of species, affecting gene flow and the long-term survival of populations. This result is consistent with research highlighting the importance of ecological corridors and habitat connectivity in mitigating the effects of fragmentation. To address this issue, future management strategies should focus on creating ecological corridors and reducing human-induced disturbances, such as road construction and urban expansion.

5.2. Ecological Functions and Forest Management

The ecological function indicators, such as NPP, soil organic matter content, and water retention capacity, also played a crucial role in supporting habitat quality. NPP, which reflects the forest's capacity for energy production, and soil organic matter, which indicates soil fertility, both had high standardized values. These findings highlight the forest's critical role in sustaining primary productivity, which supports the entire food web, from plants to herbivores and predators.

Despite the positive results, water retention capacity and carbon storage indi-

cators indicated areas for improvement. Water retention, essential for maintaining habitat stability during droughts, showed significant potential for improvement. Similarly, increasing the forest's carbon storage capacity would enhance its ability to sequester carbon, contributing to climate change mitigation efforts. These results point to the need for forest management strategies that not only focus on biodiversity conservation but also address the forest's broader ecological functions.

5.3. Socio-Economic Factors and Long-Term Habitat Quality Improvement

While the socio-economic and management indicators contributed less to the overall habitat quality index, they still play an essential role in regulating human impacts and ensuring the long-term sustainability of habitat improvements. The high contribution of community participation and the implementation of management measures suggests that local communities and effective forest management practices are crucial for ensuring that conservation and restoration efforts are successfully carried out. The positive effects of community participation in forest management have been well-documented, as local stakeholders are more likely to support and maintain management initiatives.

However, the relatively lower contribution of ecological compensation and forest product utilization indicates that further efforts are needed to ensure that these socio-economic mechanisms are effectively integrated into forest management practices. Ecological compensation policies should be strengthened to provide sustainable economic incentives for conservation and restoration, especially in regions where local livelihoods depend heavily on forest resources. Similarly, forest product utilization should be managed sustainably to prevent over-harvesting and ensure that forests continue to provide long-term ecological benefits.

5.4. Implications for Forest Management and Policy

The findings of this study have significant implications for forest management and policy, particularly in regions experiencing forest degradation and biodiversity loss. The proposed evaluation system emphasizes the importance of multi-dimensional forest management that integrates ecological, social, and economic factors. The focus on wildlife habitat quality as a core evaluation goal provides a more comprehensive and ecologically relevant framework for assessing forest management practices. By incorporating biodiversity, ecological structure, ecological functions, and socio-economic factors into the evaluation system, the study highlights the need for a holistic approach to forest management that considers the interdependence of ecosystem health, human activities, and biodiversity conservation.

The study also provides valuable insights into the role of near-natural forest management in enhancing habitat quality. The findings suggest that forest management practices that prioritize the restoration of native species, enhance forest

structure, and reduce human-induced disturbances are likely to yield the greatest benefits for wildlife habitat quality. This approach aligns with the global trend towards rewilding and ecosystem-based management practices, which aim to restore ecological processes and enhance the resilience of ecosystems to climate change.

6. Conclusions

This study presents a comprehensive forest management evaluation system centered on the improvement of wildlife habitat quality, which incorporates ecological, social, and economic dimensions into a unified framework. The proposed system emphasizes the importance of biodiversity, forest structure, and ecological functions in shaping habitat quality, while also recognizing the role of socio-economic factors in supporting long-term habitat improvements.

The key findings of this study are as follows:

- **Biodiversity and Forest Structure:** The evaluation system revealed that biodiversity, particularly plant and animal species richness, and forest structure, including canopy closure and the presence of key structural features such as large-diameter trees, standing deadwood, and downed wood, are the primary drivers of habitat quality in the study area. These elements enhance ecological complexity, creating diverse microhabitats that support a wide range of species.
- **Ecological Functions:** Indicators of ecological function, such as net primary productivity, soil organic matter content, and water retention capacity, also played significant roles in supporting habitat quality. However, opportunities for improvement remain in enhancing water retention and carbon storage, which are essential for sustaining habitat stability and contributing to climate change mitigation.
- **Socio-Economic Factors:** While socio-economic indicators, including community participation and the implementation of forest management measures, had a lower contribution to the overall habitat quality, they were essential for regulating human impacts and ensuring the long-term sustainability of habitat improvements. Effective management practices and local community involvement are key to successful conservation and restoration efforts.
- **Evaluation System Application:** The habitat quality index (HQI) calculated using the evaluation system showed that the forest management practices in the study area have led to a relatively high habitat quality. However, challenges remain in enhancing ecological functions, improving landscape connectivity, and ensuring the effective integration of socio-economic mechanisms into forest management.

This study highlights the importance of a multi-dimensional approach to forest management, one that integrates biodiversity conservation, ecosystem services, and socio-economic considerations. By focusing on wildlife habitat quality as a core objective, this evaluation system provides a more comprehensive and ecolog-

ically relevant framework for assessing forest management practices. It offers valuable insights into the role of near-natural forest management in improving habitat quality and provides a practical tool for forest managers and policymakers aiming to promote sustainable forest management and biodiversity conservation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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